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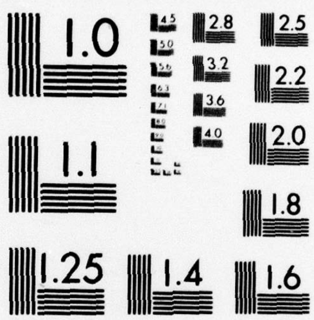

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GRAPHIC DISPLAY OF HUMAN MOTION

by

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Office of Naval Research
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Presented is the application of two and three dimensional graphic display models of a human body in studying the motion of a human being as a result of external influences. Included are an occupant during a vehicle crash and a parachutist during the opening of his chute.

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GRAPHIC DISPLAY OF HUMAN MOTION

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Presented is the application of two and three dimensional graphic display models of a human body in studying the motion of a human being as a result of external influences. Included are an occupant during a vehicle crash and a parachutist during the opening of his chute.

Key words: Graphic display of human body motion; parachutist; vehicle occupant crash simulation

1. Introduction

In simulating the motion of the human body primarily as a result of external influences, such as that occurring during a vehicle crash, the body is normally represented as a collection of rigid members (segments) connected by appropriate ball or pin joints. The positions of these segments, and thus of the entire body, is calculated as a function of time based on the dynamics of the assemblage taking into account their mass and moment of inertia, joint properties, etc. The results of the simulation include, among other information, the position and orientation of each segment of the body at discrete increments of time. If these are output in numerical form, little information is gained concerning the motion of the body. Some form of graphical display greatly enhances the understanding of this motion. The research presented in this paper deals with the display of these simulation results in a realistic human form on an inexpensive storage type graphic computer terminal and the generation of motion pictures therefrom.

We have previously reported the development of a general two dimensional human display model [1] and its application to occupant crash simulation through the programs SIMULA [2] and PROMETHEUS [3]. More recently a three dimensional model was developed [4] and improved [5]. In the two dimensional model the side view of the human form was represented. Here the most difficult task was to develop realistic joints which could be used for any relative position between adjacent body segments. This was accomplished through a combination of circular arcs and straight line representations. The result is a realistic looking human body in any position as shown in figures 1 and 2. In the three dimensional display model, an additional difficulty was to represent each of the body segments in a realistic form. This was accomplished using non-uniform elliptic cylinders. These are cylinders whose two ends are ellipses of different size and shape. The surface of the cylinders is expressed mathematically as:

$$X = (1-s)(A_1 \cos t_1 + C_1) + s(A_2 \cos t_2 + C_2) \quad (1)$$

$$Y = (1-s)\, B_1 \sin t_1 + s\, B_2 \sin t_2 \tag{2}$$

$$Z = (1-s)\, L_1 + s\, L_2 \tag{3}$$

in terms of the parametric coordinates s, t_1 and t_2. The quantities A_1, A_2, B_1, B_2, C_1, C_2, L_1 and L_2 are constants. In order that these equations define a surface the following relationship must hold between t_1 and t_2:

$$A_2\, B_1 \tan t_2 = A_1\, B_2 \tan t_1 \tag{4}$$

By adjusting the quantities A_1 through L_2, the surface of each of the body segments can be represented fairly accurately. Further details concerning this

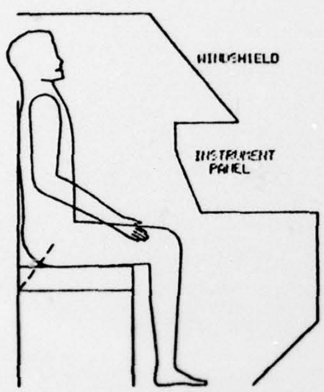

Figure 1: Two Dimensional Display

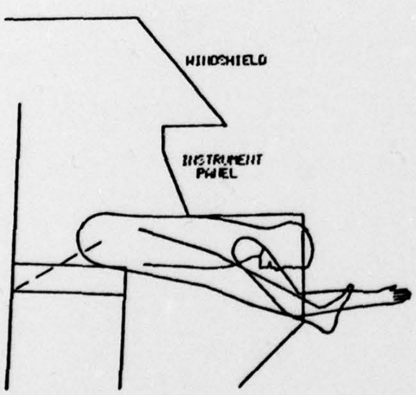

Figure 2: Two Dimensional Display

representation can be found in references [4] and [5]. The display program for the three dimensional model was written so that the user could rotate the body and look at it from any orientation. The actual display involves the outline (or shadow lines) of each body segment as well as realistic joints similar to those for the two dimensional model. A sample result is shown in figure 3.

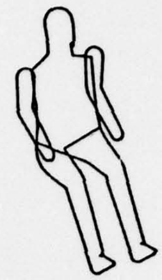

Figure 3: Typical Three Dimensional Display

2. Applications

Two versions of the three dimensional display program have been written. One displays the results of the Calspan occupant crash simulation program [6]. Here the body is represented as fifteen rigid segments:

- three torso segments
- neck
- head
- two upper arms
- two lower arms
- two upper legs
- two lower legs
- two feet

The size of the body, and thus of each segment, is based on a 50th percentile individual. The standard output from the Calspan program is used as the input to the display program. This includes the X, Y, Z position of the center of each segment and its three orientation angles measured relative to the vehicle. If α, β, and γ are the three angles, and defining:

$$\begin{aligned} C1 &= \cos(\alpha) & S1 &= \sin(\alpha) \\ C2 &= \cos(\beta) & S2 &= \sin(\beta) \\ C3 &= \cos(\gamma) & S3 &= \sin(\gamma) \end{aligned} \tag{5}$$

then the direction cosine matrix giving the orientation of each segment is:

$$D = \begin{bmatrix} C2\ C3 & S1\ S2\ C3+C1\ S3 & -C1\ S2\ C3+S1\ S3 \\ -C2\ S3 & -S1\ S2\ S3+C1\ C3 & C1\ S2\ S3+S1\ C3 \\ S2 & -S1\ C2 & C1\ C2 \end{bmatrix} \tag{6}$$

The other version of the three dimensional display program plots the results of the UCIN (University of Cincinnati) simulation program [7, 8]. In this version, the body is divided into only 13 segments (as was standard with the original UCIN program, although the current version can handle

any number of segments). Here the neck and head are combined into one segment, and the feet are attached to the lower legs to form a single segment. Also in the standard version of the UCIN program the angular position of the segments are defined differently from the Calspan model. As a result the direction cosine matrix is the transpose of the one required for the Calspan version, i.e. eq (6). Also, the angles produced by the UCIN program are relative to the position of the adjacent segment of the body. Thus, in order to obtain the absolute direction cosine matrix for a particular segment, the relative direction cosine matrix for that segment [calculated as the transpose of eq (6)] must be multiplied by the absolute matrix for the previous segment. Since everything is based on the position of the lower torso segment, then the absolute direction cosine matrix of the center torso segment is:

$$\overline{D}_{CT} = D_{CT}\,\overline{D}_{LT} \tag{7}$$

where $\overline{D}_{CT}$ and $\overline{D}_{LT}$ are the absolute direction cosine matrices for the center and lower torso segments respectively and D_{CT} is the relative direction cosine matrix for the center torso. Similarly for the lower arm (for example):

$$\overline{D}_{LA} = D_{LA}\,D_{UA}\,D_{UT}\,D_{CT}\,\overline{D}_{LT} \tag{8}$$

where the subscripts are LA - lower arm, UA - upper arm and UT - upper torso.

An additional difference between the normal Calspan and UCIN output is that the unrotated position (zero rotation angles) of the body in the Calspan program in a standing human with arms at the side. In the UCIN crash program the unrotated position is a seated individual with upper arms horizontal and lower arms pointing up. This results in some additional changes to the UCIN direction cosine matrices to make them compatible with the Calspan version.

Both the Calspan and UCIN display programs have been used to display various crash sequences, from which movies have been generated by photographing the terminal screen. Figures 4 through 8 show a 30 mph head-on collision into a wall taken from the UCIN program.

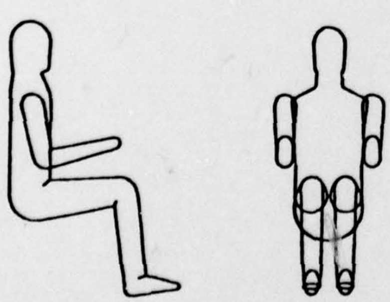

Figure 4: 30 MPH Head-On Collision

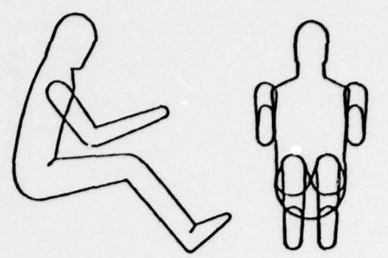

Figure 5: 30 MPH Head-On Collision

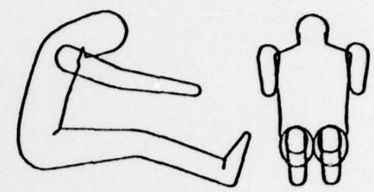

Figure 6: 30 MPH Head-On Collision

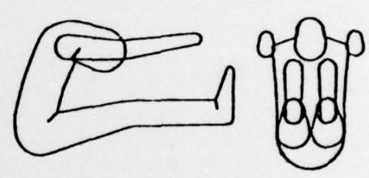

Figure 7: 30 MPH Head-On Collision

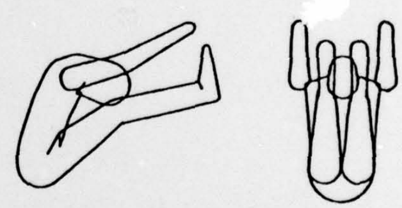

Figure 8: 30 MPH Head-On Collision

The UCIN program can also be used to simulate other types of human motion. Recently a simulation was done of a parachutist [9] during the short interval of time (400 milliseconds) that his chute is opening. In order to display the results of this simulation, some minor modifications were required in the UCIN display program. In this case, the unrotated position is a standing body similar to Calspan's program. Also, a separate neck segment was used. Figures 9 through 12 show the resulting motion, where a parachute has been included to add realism and a clock to give a better indication of time in the resulting movie.

Another version of the UCIN program called

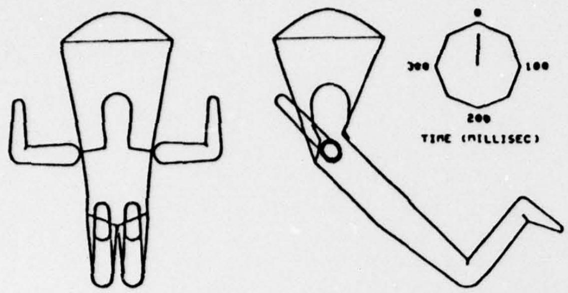

Figure 9: Parachutist

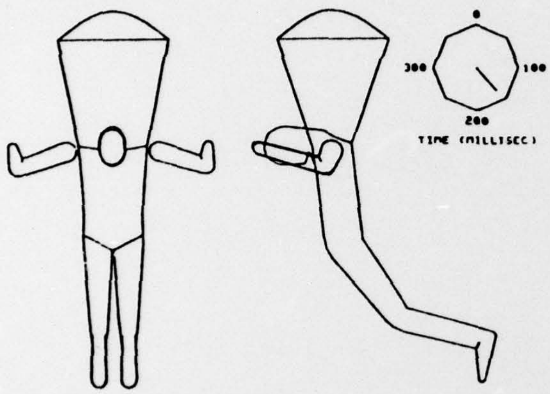

Figure 10: Parachutist

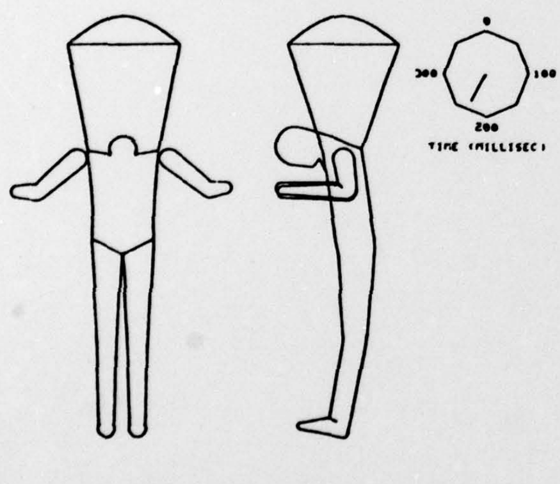

Figure 11: Parachutist

UCIN-NECK [10] was developed to better simulate the motion of the head and neck on an assumed rigid torso. Here the head and seven vertebrae in the neck were approximated by rigid segments, connected in such a way as to allow relative displacement as well as rotation between the segments.

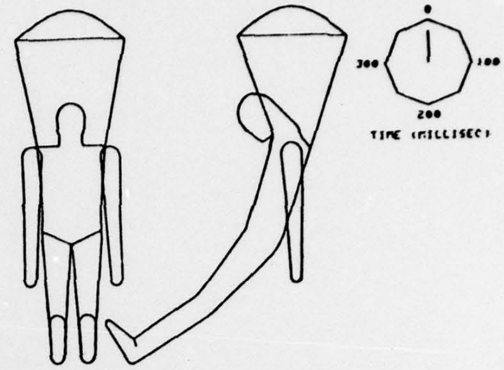

Figure 12: Parachutist

In order to display the results of this program on a graphic terminal, a special two dimensional head-neck display program was written. Figures 13 through 16 show a typical deceleration simulation that results.

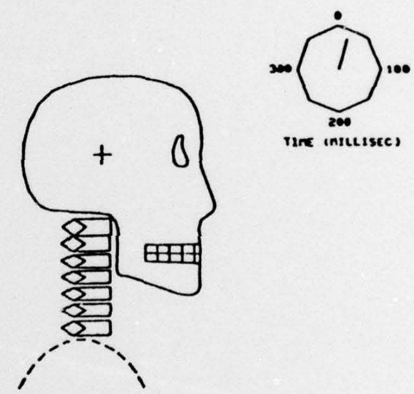

Figure 13: Head-Neck Simulation

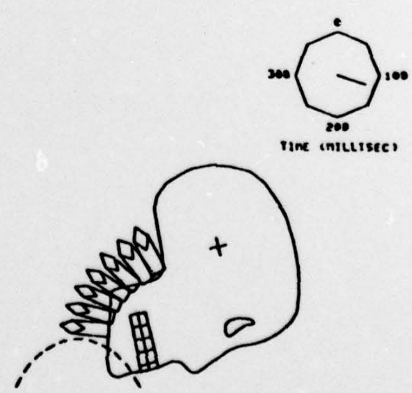

Figure 14: Head-Neck Simulation

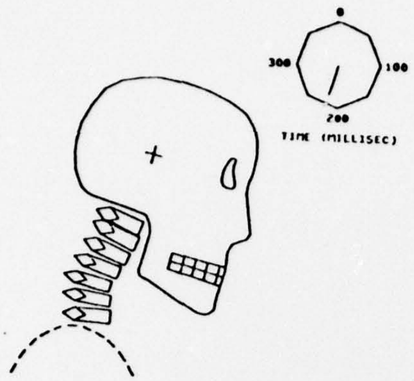

Figure 15: Head-Neck Simulation

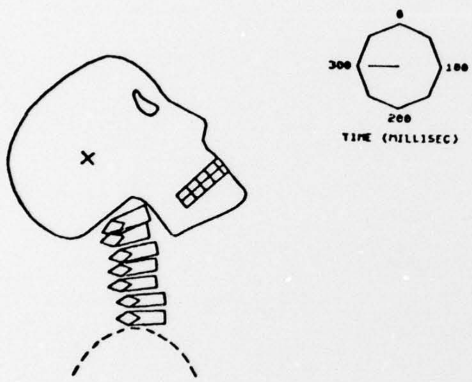

Figure 16: Head-Neck Simulation

3. Conclusions

Using a graphic computer terminal and the two and three dimensional human display models developed in this work, much additional information can be gained concerning the motion of the human body subjected to external influences. Adding the graphic output and motion picture generation capabilities greatly enhances any human motion simulation program. The resulting displays can be very useful to designer of vehicle cabins, parachutes, restraint systems, or any physical components with which the body interacts.

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